POLARIZATION CHARACTERISTICS OF OCEAN FRONTAL FEATURES ASSOCIATED WITH AIRBORNE RADAR IMAGERY

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LONG-TERM GOAL

Our long-term goal is to contribute to the development of techniques and instrumentation for radar remote sensing of the ocean surface. This study involves the use of multiple-polarization, real-aperture, airborne imaging radars for remotely detecting and tracking submesoscale oceanic processes, such as water-mass fronts and surfactant slicks. We seek a better understanding of the interaction between polarized electromagnetic waves, the ocean surface, and hydrodynamic flows. The results of our study should help to design optimal radar system configurations for remotely sensing ocean surface parameters in the future.

SCIENTIFIC OBJECTIVES

Our objective is to determine which radar polarizations and illumination geometries (resolution cell sizes, azimuth and elevation illumination angles) are best suited to detecting and tracking water-mass fronts, surfactant slicks, and other submesoscale processes. The intensity of the electromagnetic wave scattered from the ocean surface is strongly dependent on the polarization orientation of the incident electric field and on the size, shape, and orientation of the dominant scatterers on the surface. Oceanic flows roughen the ambient surface wave field and create non-Bragg scatterers. These processes are detectable in radar imagery provided their scattering characteristics produce sufficient image contrast against the ambient (Bragg-scatterer) wave background. Bragg waves preferentially scatter vertical (V) polarization over horizontal (H) polarization, especially at low grazing angles, whereas non-Bragg structures, such breaking waves may scatter V and H polarizations with equal intensity. We are measuring the polarization scattering characteristics of water-mass fronts and other submesoscale processes that manifest themselves in airborne radar imagery, under a variety of wind and wave conditions to determine which radar polarizations and measurement geometries are best suited to detecting different these processes.

APPROACH

We are developing a dual-polarization X-band imaging radar test bed and operating this instrument in numerous flights over the ocean to collect simultaneous vertical (V) and horizontal (H) polarized images of the ocean surface under varying wind and wave conditions and at different radar antenna azimuth and elevation illumination angles. We are collaborating with the Remote Sensing Division of NRL in this work.

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WORK COMPLETED

We modified NRL's X-band airborne Real Aperture Radar (RAR) system to enable simultaneous imaging of the ocean surface at V and H-polarizations. This was accomplished by installing ferrite latching circulators in the radar transmitter and using a dual polarized fan beam antenna. We also developed software for displaying images in real-time and for post-flight data reduction and analysis.

We successfully operated this instrument from Navy P-3 aircraft during the NRL/ONR Chesapeake Bay Outflow Plume Experiments (COPE) in September of 1996 and May of 1997. During these flights, we collected numerous images of cusp-shaped frontal features associated with the outflow plume, many images visually associated with color fronts, and many having foam and weed lines. The aircraft flights were coordinated with ship-based observations of ocean surface salinity, wind speed, temperature, and currents. The measurements were also coordinated with ship-based radars and with an airborne SAR.

Fifty percent of our data has been reduced to dual-polarization images of the ocean surface. We collected data for calibrating the RAR by over-flying an array of trihedral corner reflectors placed on an aircraft runway. We are currently reducing this data so that the RAR images can be absolute-calibrated.

RESULTS

Figure 1 shows an example of the radar signal scattered from the ocean surface during a P-3 flight over the mouth of the Chesapeake Bay. The purpose of this flight, conducted during COPE2, was to map the location of the frontal boundary formed where the plume of outflowing fresh bay water interacts with the higher salinity waters of the continental shelf. The vertically polarized echo is shown in the upper curve, while the horizontally polarized echo is shown in the lower curve. These curves describe the variation in received power (dBm) versus time during a 500 meter-long transect over the front. (These curves are not absolute-calibrated; the top curve has been offset vertically from the lower curve to enable the dynamic ranges of the echo signals to be compared at the two polarizations.) Front crossings occurred at 280 meters and 700 meters cross-range, and surfactant slicks were crossed at 470 meters and 610 meters cross-range. This data was collected at an antenna depression angle (sea surface grazing angle) of 20 degrees. The highest signal levels for each polarization occur during the front crossing, and the lowest levels occurred when the slicks were crossed.

Differences in the radar signals scattered from the ocean surface at the two polarizations are striking. The dynamic range of the V polarized signal is approximately 20 dB, whereas that for horizontal polarization exceeds 30 dB. Horizontally polarized echo levels exceed the ambient background wave echo by 15 dB and nearly 30 dB during the two front crossings, whereas at vertical polarization, the front echo exceeds the background echo by only 5-10 dB. Fronts are thus more clearly delineated from background waves at horizontal polarization. The contrast between the ambient background echo level and the slick echo ranges between 5 and 10 dB at vertical polarization and from 2 to 5 dB at horizontal polarization, indicating that surfactant slicks are more easily detected at vertical than horizontal polarization.

Small-scale wave breaking is thought to occur at the plume front, and the radar echo from breaking waves, is a non-Bragg, weakly polarization-sensitive scattering mechanism. Bragg scattering from the ambient wave background, in contrast, is strongly polarization sensitive, with vertical polarization predicted to yield substantially larger echo levels than horizontal polarization, especially at small grazing angles. This scattering picture predicts larger front-to-background echo ratios for horizontal polarization than vertical polarization and is in qualitative agreement with our measured observations.

Surfactant films suppress Bragg wave formation through Marangoni damping, and the corresponding slick patches appear as areas of low signal intensity in radar imagery. Most of the slick echoes that we have studied have produced scattered power levels that are below the thermal noise floor of our radar receiver. Consequently, our ability to detect these features in the images is limited by the contrast between the ambient wave background and the receiver noise floor. This contrast is higher for the vertical polarized measurements because the ambient Bragg-wave background is higher for that case than for the H polarized case.

The curves shown in this example are typical for the data set collected during the COPE experiments at the 20 degree grazing angle. Our continuing work will be to absolute-calibrate this data and examine how these signal characteristics vary with antenna incidence angle, azimuth angle, and surface winds.

IMPACT/APPLICATION

Our experimental results are in qualitative agreement with current scattering models. These results suggest that V and H polarized imaging radars are each better suited to detecting a different oceanic process. Horizontal polarization is better suited to detecting, tracking, and mapping frontal boundaries, whereas vertical polarization is better suited to mapping surfactant slicks.

TRANSITIONS

The dual polarized radar and software that we have developed are currently being used in the NRL/ONR Coastal Remote Sensing ARI (CoRes), of which the COPE experiments are a part.

We plan to collaborate with NRL (M. Sletten and others in the Remote Sensing Division) in the NATO-Rapid Environmental Assessment Program during winter 1997 in the North Atlantic off the coasts of Spain and Portugal. The RAR will be used for repeat-pass imaging to map the advection of surfactant slicks for determining surface currents. The University of Massachusetts' C-band scatterometer (C-Scat) will also be used in this experiment to map the anisotropic variation in ocean normalized radar cross section, from which the surface stress will be obtained. This program is awaiting funding authorization.

RELATED PROJECTS

We have submitted a DURIP proposal to ONR for funds to develop a fully polarimetric RAR. The proposed instrument will be able to determine the complete polarimetric response of the ocean surface on a pixel-by-pixel basis. It will also use a wireless local area network (WLAN) to telemeter images to ships in near-real time. This will enable a more effective collaboration between aircraft and ship-based experimenters in oceanographic experiments.

Since 1990, we have been working with the USAF/Rome Laboratory to determine the polarimetric scattering behavior of terrain at bistatic angles.

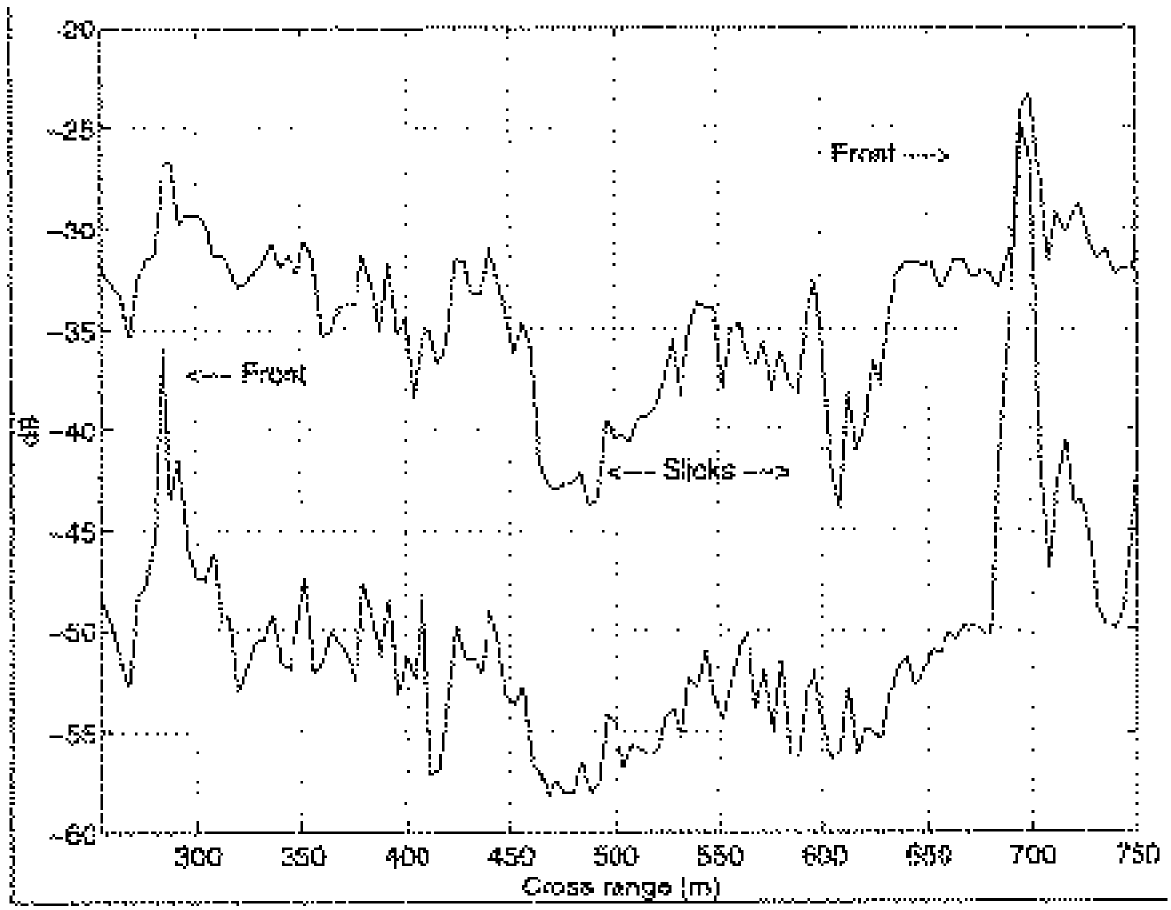

Figure 1. Received Power (log scale) versus Cross-range over 500 m Transect at Vertical (upper curve) and Horizontal (lower curve) Polarizations.